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# REESTABLISHMENT OF *ERIASTRUM HOOVERI* (POLEMONIACEAE) FOLLOWING OIL FIELD DISTURBANCE ACTIVITIES

GARY L. HOLMSTEAD
Idaho Power Company, Environmental Affairs Department,
1221 West Idaho Street, Boise, ID 83702

DAVID C. ANDERSON
EG&G Energy Measurements, Inc., 101 Convention Center Drive,
Las Vegas, NV 89109

ABSTRACT

Little is known about the ecology of *Eriastrum hooveri* (Jepson) H. Mason or about its tolerance to oil field related habitat disturbance. Taylor and Davilla (1986) suggested the species was closely associated with dense cryptogamic soil crust, characteristic of undisturbed sites. We monitored reestablishment of *E. hooveri* on two sites disturbed by construction activities (a pipeline and a well pad) at the U.S. Department of Energy's Naval Petroleum Reserve No. 1, Kern County, CA. Before construction, topsoil from the sites was stockpiled. After construction, the topsoil was replaced, and the pipeline site and a portion of the well pad site were seeded with a mix of native shrub, grass, and forb species. Part of the well pad site was left unseeded so that reestablishment of *E. hooveri* could be compared between seeded and unseeded plots. Sites were monitored during the first two growing seasons following disturbance (1991 and 1992). Vegetation characteristics of the disturbed sites were compared with adjacent undisturbed habitat. *Eriastrum hooveri* recolonized both disturbed sites in the first growing season. Generally, the density and frequency of occurrence of *E. hooveri* on our transects increased from the first to the second growing season. Cryptogamic crust cover was low (≤4.6%) on both the disturbed and undisturbed sites in both years. Our observations suggest that 1) *E. hooveri* is able to quickly recolonize heavily disturbed sites, at least if topsoil is conserved and weather conditions are favorable; and that 2) cryptogamic crust cover may not be as important a correlate with the occurrence of *E. hooveri* as previously thought.

*Eriastrum hooveri* (Jepson) H. Mason (Hoover's woolly-star) is a small annual herb of the Polemoniaceae and endemic to the San Joaquin Valley, California. It was federally listed as threatened in July 1990, due to threats of agricultural land conversion, urbanization, reservoir construction, and oil and gas development (U.S. Fish and Wildlife Service 1990). Little is known about the ecology of *E. hooveri*. Taylor and Davilla (1986) provided some general observations on germination, soil seed reserves, growth phenology, and reproduction of the species.

Early observations by Taylor and Davilla (1986) typically associated *E. hooveri* populations on sites without dense annual plant cover and with dense cryptogamic soil crusts (eucaryotic algae, lichens, bryophytes, cyanobacteria, and fungi), which normally take several years to develop (Anderson et al. 1982a). A 1988 reconnaissance survey of NPR-1 (EG&G Energy Measurements 1988) and on-going surveys of NPR-1 (EG&G Energy Measurement 1992) have identified several *E. hooveri* populations in formerly disturbed sites. Most of these sites are on or near abandoned or infrequently-used roadways, suggesting that the species can respond favorably to disturbance. *Eriastrum hooveri* response to disturbance has not been experimentally investigated.

In this paper, we evaluate the reestablishment of *E. hooveri* on two oil field construction projects, an underground pipeline and a well pad, during the first two growing seasons following disturbance. We describe the chronology of each disturbance and subsequent restoration activities; and we compare the density and frequency of occurrence of *E. hooveri*, and other characteristics of associated vegetation, between the disturbed sites and adjacent undisturbed habitat.

On the well pad site, experimental plots were used to compare reestablishment of *E. hooveri* between plots of seeded topsoil (i.e., replaced topsoil seeded with a mix of shrub, grass, and forb species) and unseeded topsoil. We hypothesized that by not seeding the conserved topsoil, plant competition would be reduced and *E. hooveri* reestablishment would be enhanced.

*Study area.* The majority of the San Joaquin Valley is cultivated and very few remnants of native plant communities remain (Preston 1981). Although NPR-1 is an active oil and gas producing facility, it encompasses large tracts of native and naturalized vegetation in the San Joaquin Valley. It is located approximately 40 km southwest of Bakersfield, Kern County, CA, and consists of 19,120 ha. NPR-1 is located on the Elk Hills formation, which is in the most arid portion of cismontane California (Major 1977). Geomorphologically, the Elk Hills constitute a subsidiary upland of the Inner South Coast Ranges. The main ridge, oriented in a

TABLE 1. LIST OF SPECIES AND SEEDING RATES USED TO SEED REDISTRIBUTED TOPSOIL ON THE PIPELINE STUDY SITE (DECEMBER 1990) AND THE WELL PAD STUDY SITE (JANUARY 1991), NAVAL PETROLEUM RESERVE NO. 1, KERN COUNTY, CA. [a] PLS = Pure Live Seed, which equals (purity × germination)/100.

| Study site | Life-form | Scientific binomial | kg PLS[a]/ha | PLS[a] /m² |
|---|---|---|---|---|
| a. Pipeline | Shrub | *Atriplex polycarpa* (Torrey) S. Watson | 1.1 | 16 |
| | | *Atriplex lentiformis* (Torrey) S. Watson | 0.6 | 5 |
| | | *Eriogonum fasiculatum* (Benth.) Torrey & A. Gray | 4.5 | 344 |
| | | *Isomeris arborea* Nutt. | 3.4 | 5 |
| | Grass | *Vulpia myuros* (L.) C. Gmelin | 1.1 | 198 |
| | Forb | *Lupinus densiflorus* Benth. | 0.5 | 3 |
| | | *Phacelia tanacetifolia* Benth. | 0.5 | 107 |
| b. Well Pad | Shrub | *Atriplex polycarpa* (Torrey) S. Watson | 2.3 | 32 |
| | | *Eriogonum fasiculatum* (Benth.) Torrey & A. Gray | 4.5 | 344 |
| | | *Isomeris arborea* Nutt. | 3.4 | 5 |
| | Grass | *Vulpia myuros* (L.) C. Gmelin | 1.1 | 198 |
| | Forb | *Trifolium hirtum* All. | 1.1 | 34 |
| | | *Lupinus densiflorus* Benth. | 0.5 | 3 |
| | | *Phacelia tanacetifolia* Benth. | 0.5 | 107 |

northwest-southeast direction, is flanked by deeply incised canyons and subsidiary ridges. The ridges and drainages extend into gently sloping, alluvial plains along the outer boundaries. Elevations range from 93 to 473 m above sea level.

NPR-1 lies within the Valley Grassland vegetation type (Heady 1977). Dominant shrubs include *Atriplex polycarpa* (Torrey) S. Watson, *Hymenoclea salsola* A. Gray, and *Isomeris arborea* Nutt. Herbaceous cover is dominated by *Bromus madritensis* L. and *Erodium cicutarium* (L.) L'Hér.

The climate in this region is hot and dry in summer, and cool and wet in winter with frequent fog. Temperatures in summer often exceed 38°C, and seldom go below 0°C in winter. Precipitation occurs primarily as rain falling between November and April (O'Farrell et al. 1987). Since 1981, when weather data collection began on NPR-1, annual precipitation has averaged 124 mm and ranged between 51 and 226 mm.

## METHODS

*Pipeline study site*. In 1990, a gas company completed construction along two underground natural gas pipelines that crossed NPR-1. A large diameter pipeline was installed to replace a small pipeline constructed in 1930. A small pipeline, located approximately 1 km away, was also removed. The construction corridor along the pipelines ranged between 15–20 m wide, and was approximately 38 km long. Approximately 7 ha of habitat containing *E. hooveri* populations were disturbed within the pipeline corridors. Construction activities were delayed until August, several months after the typical flowering season for *E. hooveri* (April–May), to allow existing *E. hooveri* plants to set seed.

Prior to pipeline trenching operations, a road grader was used to scrape 7–8 cm of topsoil to the edge of the construction corridor in all *E. hooveri* habitat. A road grader was then used to replace the topsoil following construction. Due to the deep, powdery nature of the disturbed soil, straw mulch was applied at a rate of about 9,000 kg/ha to improve soil structure. Straw was crimped into the soil using a sheep's foot-type roller-crimper. All *E. hooveri* habitat was drill seeded with a mix of shrubs, forbs, and grasses at a rate of 11.2 kg of pure live seed (PLS) per hectare (Table 1a). Seeding was completed in December 1990.

In spring 1991, the length of the pipeline corridor in *E. hooveri* habit was divided into 0.1 km segments and ten segments were randomly selected. In each segment a random starting point was selected. At each starting point, two parallel 25-m line transects were established to monitor vegetation. One transect was located outside of the pipeline corridor in undisturbed habitat, and the other transect was located down the centerline of the reclaimed pipeline corridor. Vegetation was sampled along each transect in the spring of 1991 and 1992. An ocular point projection device (ESCO Associates Inc., Boulder, CO) was used to estimate ground cover. A total of 100 points or "hits" (a dimensionless plot such as a point frame-type sample) were sampled along each transect; 10 points at 2.5 m intervals. Points were recorded as bare ground, litter, cryptogamic crust, or live vascular plant material, by species. The elements classified as litter included both dead standing and detached biomass. Cryptogamic crust included just those elements that are identifiable in the field, without magnification. The density of *E. hooveri* was determined by recording the number of plants that occurred within a 2 × 25 m belt transect. The densities of grasses and forbs were determined by counting the number of individual plants within five 1 × 1 m quadrats placed at 5 m intervals along the transect. *Eriastrum hooveri* frequency was estimated by using five 1 × 1 m quadrats placed at 5 m intervals along each transect, and counting the number of quadrats containing *E. hooveri*. Frequency of occurrence was expressed as the percentage of quadrats containing *E. hooveri*.

*Well pad study site*. A second study site was established near a new water well. In July 1990, construction began on the well before a biological survey was conducted. About half of the area proposed for the well pad (0.4 ha) was scraped and 8–10 cm of topsoil was stockpiled. A survey of the site identified several small stands (5–50 plants each) of *E. hooveri* in the surrounding undisturbed areas of the well pad site. To avoid further disturbance to this *E. hooveri* population, the new well was relocated to a nearby existing well pad. After consultation with the U.S. Fish and Wildlife Service, the U.S. Department of Energy established vegetation monitoring transects at the original well site to document reestablishment of *E. hooveri*.

In August 1990, the stockpiled topsoil was spread back over the disturbed area, and the site was divided into nine study plots, about 10 × 50 m each. Three disturbed plots were drill seeded in January 1991 with a mix of shrubs, forbs, and grasses at a rate of 13 kg of PLS/ha (Table 1b), straw mulched at a rate of about 3,400 kg/ha, and crimped. Three disturbed plots were not seeded, and three plots were selected in adjacent undisturbed *E. hooveri* habitat. Due to the pattern of disturbance created by construction equipment, plots were arranged side by side starting with a seeded topsoil plot adjacent to unseeded topsoil plot, which was then adjacent to undisturbed habitat. This order of treatments was replicated three times.

A permanent 25-m line transect was established down the centerline of each plot to monitor vegetation. A random starting location was selected for the first transect and all additional transects were aligned parallel to the first. Vegetation was monitored in the spring of 1991 and 1992 using the methods previously described for the pipeline study site.

*Precipitation data*. Monthly precipitation was recorded with an All Weather Rain Gauge (Productive Alternatives, Inc., Fergus Falls, MN) at eight stations on NPR-1. Total annual precipitation is expressed on a water-year (WY) basis (e.g., WY91 = 1 July 1990 to 30 June 1991).

*Data analysis*. On the pipeline site, the density and frequency of *E. hooveri*, and other vegetative characteristics (e.g., total plant cover, cryptogamic cover, density of grasses and forbs) were compared between undisturbed habitat and seeded topsoil plots. On the well pad site, the density and frequency of *E. hooveri*, and vegetative characteristics were compared between undisturbed habitat, seeded topsoil, and unseeded topsoil plots. On each study site, and for each plot type, the effects of year (1991 and 1992) and treatment were evaluated using repeated measures analysis of variance. On the well pad site, linear contrasts between treatments were used to separate mean values. Means were considered significantly different at alpha ≤0.05. SAS/STAT v.6 software (SAS Institute Inc. 1990) was used to perform statistical computations.

## Results

Annual precipitation was 137 mm in WY91 (10% above average) and 155 mm in WY92 (25% above average).

*Pipeline study site*. *Eriastrum hooveri* was present on all transects on the seeded topsoil plots and undisturbed habitat in 1991 and 1992. The density and frequency of *E. hooveri* plants increased significantly from 1991 to 1992 and were significantly higher on the undisturbed habitat (Table 2a). From 1991 to 1992, density of *E. hooveri* on the undisturbed habitat increased from 2.1 to 5.3 plants/m$^2$, and on the seeded topsoil plots it increased from 0.1 to 0.9 plants/m$^2$ (Fig. 1a). Between 1991 and 1992, the frequency of *E. hooveri* increased from 38 to 68% on the undisturbed habitat, and from 18 to 26% on the seeded topsoil plots (Fig. 1a).

Total plant cover and density of grasses and forbs increased significantly from 1991 to 1992 and were higher on the undisturbed habitat (Table 2a). From 1991 to 1992, total plant cover, and the density of grasses and forbs generally increased significantly in both treatments (Table 3a).

In 1991, cryptogam cover was 4.6% on the undisturbed habitat, and absent on the seeded topsoil plots. In 1992, cryptogam cover was 1.3% on the undisturbed habitat and 0.5% on the seeded topsoil plots (Table 3a).

*Well pad study site*. As on the pipeline site, *E. hooveri* was present on all transects in both disturbed and undisturbed habitat in 1991 and 1992. The density of *E. hooveri* increased significantly from 1991 to 1992, but frequency of *E. hooveri* was not significantly different between years (Table 2b). The density and frequency of *E. hooveri* plants were not significantly different between treatments (Table 2b). From 1991 to 1992, density of *E. hooveri* increased from 0.8 to 1.9 plants/m$^2$ on the undisturbed habitat, increased from 0.4 to 2.3 plants/m$^2$ on the seeded topsoil plots, and increased from 0.4 to 4.0 plants/m$^2$ on the unseeded topsoil plots (Fig. 1b). From 1991 to 1992, the frequency of *E. hooveri* increased from 46.7 to 53.3% on the undisturbed habitat, decreased from 46.7 to 6.7% on the seeded topsoil plots, and increased from 26.7 to 33.3% on the unseeded topsoil plots (Fig. 1b).

Total plant cover and density of grasses and forbs increased significantly from 1991 to 1992 and were highest on the undisturbed habitat (Table 2b). From 1991 to 1992, total plant cover and density of grasses and forbs increased significantly in all treatments (Table 3b).

Total plant cover and density of grasses and forbs were higher on the seeded topsoil plots compared to the unseeded topsoil plots, but only total plant

TABLE 2. SUMMARY OF REPEATED MEASURES ANALYSIS OF VARIANCE ON THE EFFECTS OF YEAR AND TREATMENT ON *ERIASTRUM HOOVERI* DENSITY AND FREQUENCY, AND KEY VEGETATION CHARACTERISTICS ON THE PIPELINE AND WELL PAD STUDY SITES, NAVAL PETROLEUM RESERVE NO. 1, KERN COUNTY, CA. [a] Factors are listed in decreasing order of mean values where UND = undisturbed habitat, ST = seeded topsoil, and UST = unseeded topsoil. Factors differing significantly (P < 0.05, linear contrasts) are indicated by ">".

| Study site | Characteristic | Factor | P value | Mean difference[a] |
|---|---|---|---|---|
| a. Pipeline | *E. hooveri* | Year | <0.001 | 1992 > 1991 |
| | Density | Treatment | 0.006 | UND > ST |
| | | Year × Treatment | 0.012 | |
| | *E. hooveri* | Year | 0.007 | 1992 > 1991 |
| | Frequency | Treatment | 0.003 | UND > ST |
| | | Year × Treatment | 0.094 | |
| | Total Plant Cover | Year | <0.001 | 1992 > 1991 |
| | | Treatment | 0.346 | UND = ST |
| | | Year × Treatment | 0.053 | |
| | Grass Density | Year | 0.013 | 1992 > 1991 |
| | | Treatment | 0.221 | UND = ST |
| | | Year × Treatment | 0.011 | |
| | Forb Density | Year | <0.001 | 1992 > 1991 |
| | | Treatment | 0.001 | UND > ST |
| | | Year × Treatment | 0.933 | |
| b. Well Pad | *E. hooveri* | Year | 0.008 | 1992 > 1991 |
| | Density | Treatment | 0.538 | UST = UND = ST |
| | | Year × Treatment | 0.249 | |
| | *E. hooveri* | Year | 0.436 | 1992 = 1991 |
| | Frequency | Treatment | 0.374 | UND = UST = ST |
| | | Year × Treatment | 0.199 | |
| | Total Plant Cover | Year | <0.001 | 1992 > 1991 |
| | | Treatment | 0.002 | UND > ST > UST |
| | | Year × Treatment | 0.003 | |
| | Grass Density | Year | <0.001 | 1992 > 1991 |
| | | Treatment | 0.006 | UND > ST = UST |
| | | Year × Treatment | 0.024 | |
| | Forb Density | Year | 0.008 | 1992 > 1991 |
| | | Treatment | 0.538 | UND = ST = UST |
| | | Year × Treatment | 0.249 | |

cover was significantly higher (Table 2b). Density and frequency of *E. hooveri* were higher on the unseeded topsoil plots compared to the seeded topsoil plots, but these differences were not significant (Table 2b).

No cryptogamic soil crust was observed on any of the plots in 1991. In 1992, cover of cryptogams was 2.0% on the seeded topsoil plots, 1.0% on the unseeded topsoil plots, and 0.7% on the undisturbed habitat (Table 3b).

## DISCUSSION

Although these investigations are opportunistic in nature in that they were conducted without the opportunity to set up ideal experimental conditions, some observations can be made. These observations should be substantiated with appropriate experimental studies.

The results of this investigation demonstrate that *E. hooveri* can quickly colonize disturbed sites, at least when topsoil is conserved and returned, and adequate rainfall is received. At both study sites, *E. hooveri* occupied all disturbed plots after one growing season, and its density increased on the disturbed plots, at both study sites, from the first to the second growing season (Fig. 1). The frequency of *E. hooveri* increased on all disturbed plots except the seeded topsoil plots on the well pad study site, from the first to the second growing season (Fig. 1).

During the first few growing seasons following disturbance, we expected that the density and frequency of *E. hooveri* on the disturbed plots would not be as high as on undisturbed habitat. This expectation was confirmed at the pipeline study site (Table 2a). However, on the well pad site, neither the density nor the frequency of *E. hooveri* were significantly different between disturbed plots and undisturbed habitat (Table 2b). The small sample sizes (n = 3) for each treatment on the well pad site probably reduced the ability to detect significant differences.

We hypothesized that by not seeding the conserved topsoil at the well pad site, plant competition would be reduced and *E. hooveri* reestablishment would be enhanced. Unseeded plots had lower plant cover and lower densities of grasses and forbs than seeded topsoil plots in both 1991 and 1992 (Table 3b). However, *E. hooveri* density and frequency were not significantly higher on the unseeded plots than on the seeded plots (Table 2b).

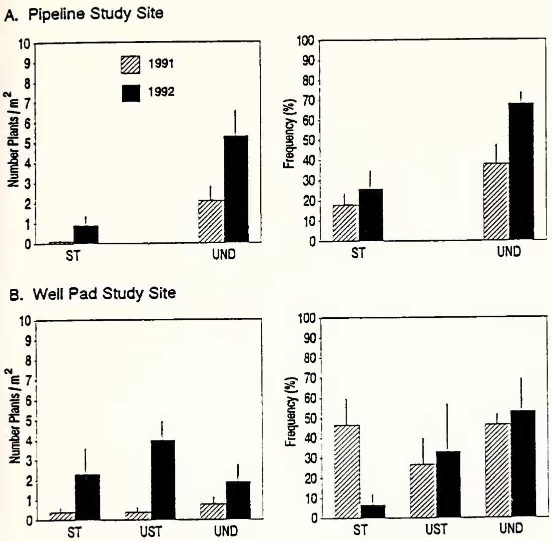


FIG. 1. Summary of *Eriastrum hooveri* density and frequency on the pipeline and well pad study sites where ST = seeded topsoil, UST = unseeded topsoil, and UND = undisturbed habitat, U.S. Naval Petroleum Reserve No. 1, Kern County, CA. Vertical bars indicate each standard error of the mean.

The capacity for *E. hooveri* to quickly invade disturbed sites is supported by other observations on NPR-1. In spring 1992 we observed seven populations of *E. hooveri* within a firebreak corridor that is maintained around the perimeter of NPR-1 (Holmstead and Anderson unpublished). Various sections of the firebreak have been annually disked for many years depending on the amount of vegetative cover present on the firebreak. Since 1990, all known *E. hooveri* populations have been avoided by disking operations. However, two of the populations we observed in spring 1992 were in sections of the firebreak that had been disked in 1991 and five populations were in areas disked in 1989.

The degree of reestablishment of *E. hooveri* in this study may partially be attributable to favorable growing conditions during WY91 and WY92. Annual plant population sizes vary widely from year to year (Holland 1987), and this variation is traditionally attributed to the vagaries of annual weather. A low rainfall year may result in very low numbers of a species, or even years when no plants are observed, while a higher rainfall year may result in large numbers of a species. Taylor and Davilla (1986) observed that *E. hooveri* germinated relatively late (January–February) as opposed to after the first rainfall (October–November). In WY91, rainfall was 10% above average, and 91% (124 of 137 mm) occurred from January–March. In WY92, rainfall was 25% above average, and 80% (124 of 155 mm) occurred from January–March. Abundant rainfall in both WY91 and WY92, and concentration of this rain between January–March may have promoted high germination and establishment of *E. hooveri*.

None of the disturbed or undisturbed plots at either study site had "dense patches of abundant soil cryptogams" that Taylor and Davilla (1986) reported were a principal correlate with the presence of *E. hooveri*. Cryptogamic cover was absent on most of the plots in 1991 (Table 3). The highest percent cover of cryptogams was 4.6%, which occurred on the undisturbed plots at the pipeline study site in 1991. In 1992, average cryptogam cover was ≤2.0% on all plots. These amounts of cryptogamic cover are well below what would be considered dense cover. Mean cover of cryptogams in non-grazed areas in Utah deserts was estimated at 53.6% (Brotherson et al. 1983). Average cover of

TABLE 3. VEGETATION CHARACTERISTICS ON THE PIPELINE AND WELL PAD STUDY SITES DURING THE FIRST AND SECOND GROWING SEASONS (1991 AND 1992) FOLLOWING CONSTRUCTION ACTIVITIES, NAVAL PETROLEUM RESERVE NO. 1, KERN COUNTY, CA. Standard errors of the mean are in parentheses.

| | | 1991 | | | 1992 | | |
|---|---|---|---|---|---|---|---|
| Study site | Factor | Seeded topsoil | Unseeded topsoil | Undisturbed habitat | Seeded topsoil | Unseeded topsoil | Undisturbed habitat |
| a. Pipeline | Sample Size | 10 | — | 10 | 10 | — | 10 |
| | Cover (%) | | | | | | |
| | Total Plant | 31.3 (4.6) | — | 41.8 (1.9) | 67.6 (3.1) | — | 65.8 (4.9) |
| | Cryptogams | 0.0 | — | 4.6 (1.4) | 0.5 (0.3) | — | 1.3 (0.3) |
| | Density (no./m²) | | | | | | |
| | Grass | 24.2 (6.8) | — | 95.5 (9.6) | 124.4 (31.1) | — | 94.4 (8.6) |
| | Forb | 13.8 (2.5) | — | 61.8 (9.4) | 49.8 (9.3) | — | 98.9 (14.9) |
| b. Well Pad | Sample Size | 3 | 3 | 3 | 3 | 3 | 3 |
| | Cover (%) | | | | | | |
| | Total Plant | 26.7 (4.5) | 12.0 (1.7) | 55.0 (4.5) | 62.7 (3.6) | 55.3 (1.8) | 69.7 (3.9) |
| | Cryptogams | 0.0 | 0.0 | 0.0 | 2.0 (1.0) | 1.0 (1.0) | 0.7 (0.3) |
| | Density (no./m²) | | | | | | |
| | Grass | 21.3 (4.3) | 1.7 (0.5) | 34.5 (8.8) | 130.5 (8.5) | 85.4 (10.3) | 216.7 (31.6) |
| | Forb | 15.1 (2.2) | 7.0 (0.6) | 36.7 (5.9) | 36.7 (15.8) | 31.7 (2.8) | 61.3 (12.5) |

cryptogams on grazed sites in Utah deserts was 6.3% on light developed crusts and 20.9% on moderate-heavy developed crusts (Anderson et al. 1982b). Our observations suggest that *E. hooveri* is not restricted to dense cryptogamic soil crusts. Quantification of site characteristics associated with *E. hooveri* populations are needed.

Some explanation for the low cryptogamic cover observed in this study compared to observations by Taylor and Davilla (1986), and for cover estimates reported for other investigations of cryptogamic crusts may be explained by 1) observer variability in cover estimates, 2) differences in antecedent precipitation that might have made the crust more apparent in one sample year than another, or 3) the components of cryptogamic crusts that are included in the cover estimates. Algal cover estimates can be quite subjective since algae are less obvious than lichens and mosses and their cover estimates are dependant upon experienced observers (Anderson et al. 1982a). Cryptogamic crust is known to consist of eucaryotic algae, lichens, bryophytes, cyanobacteria, and fungi that live on and just below the soil surface (Belnap 1994). Most general field inventory investigations focus on just those crust components that are visible without magnification, while more specific research on cryptogamic crust utilize laboratory detection procedures and estimate total cover of all components. The total cover estimates referenced in this paper used similar field methods.

The occurrence of *E. hooveri* on disturbed areas, and its apparent capacity to quickly occupy disturbed sites indicate that it may not be dependent on pristine habitats or dense cryptogamic cover. Some level of disturbance may be compatible with *E. hooveri* conservation. However, long term monitoring studies of disturbed *E. hooveri* populations and recently colonized disturbed sites are warranted. Such studies should investigate the persistence and vigor (size, flowering, and fruiting) of the plants over time.

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